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SWITCHING FABRIC FOR ENERGY STORAGE AND POWER CONVERSION

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Applicant: Amber Kinetics, Inc., Union City, CA (US)

(72)

Inventor: Mike M. He, San Jose, CA (US)

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Field of Classification Search

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(56)

References Cited

U.S. PATENT DOCUMENTS

6,459,171	B1 *	10/2002	Leifer		H02J 1/10	307/24
7,612,466	B2 *	11/2009	Skutt		B60L 11/1842	307/29
8,286,006	B2	10/2012	Kreiner et al.			
8,354,825	B2	1/2013	Lee et al.			
8,643,325	B2	2/2014	Yang			
2011/0140649	A1	6/2011	Choi			
2012/0194138	A1	8/2012	Uno et al.			
2012/0274145	A1	11/2012	Taddeo			
2013/0002026	A1	1/2013	Mizutani et al.			
2013/0125546	A1	5/2013	Barmeier et al.			
2013/0285491	A1	10/2013	Kuznetsov			
2014/0117938	A1	5/2014	Ouzaarou et al.			
2014/0361624	A1 *	12/2014	Ault		H02J 9/062	307/65

OTHER PUBLICATIONS

PCT Invitation to Pay Additional Fees and, Where Applicable, Protest Fee for PCT/US2016/037770, dated Aug. 2, 2016, 2 pages.

PCT International Search Report and Written Opinion for PCT/US2016/037770, dated Oct. 7, 2016, 25 Pages.

* cited by examiner

Primary Examiner — Fritz M Fleming

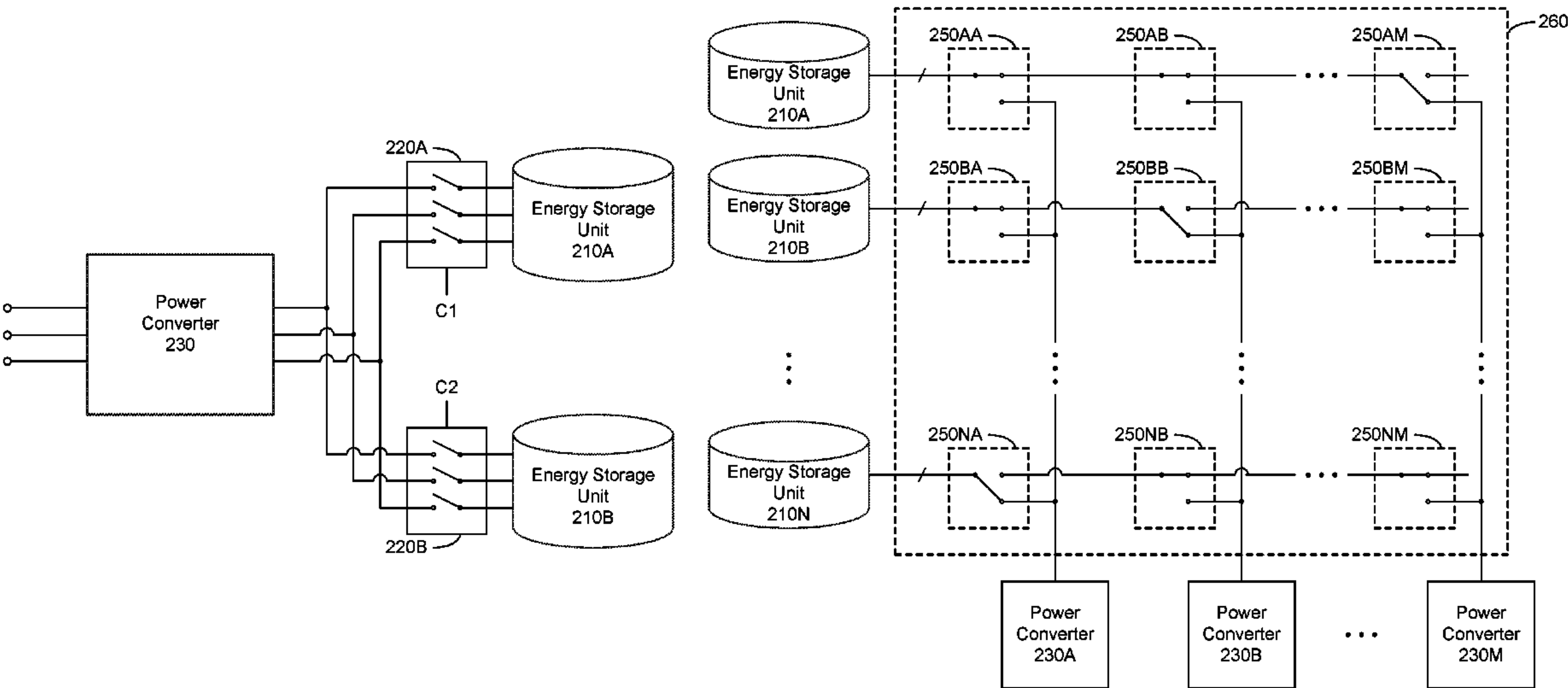
(74) Attorney, Agent, or Firm — Soquel Group LLC

(57)

ABSTRACT

An energy storage system operable in a charging phase and in a discharging phase is disclosed. The energy storage system includes M energy storage units and N power converters, where M is at least two and N is at least one. The energy storage system also includes a switching fabric that reconfigurably couples the energy storage units to the power converters and a controller that reconfigures the switching fabric.

26 Claims, 5 Drawing Sheets



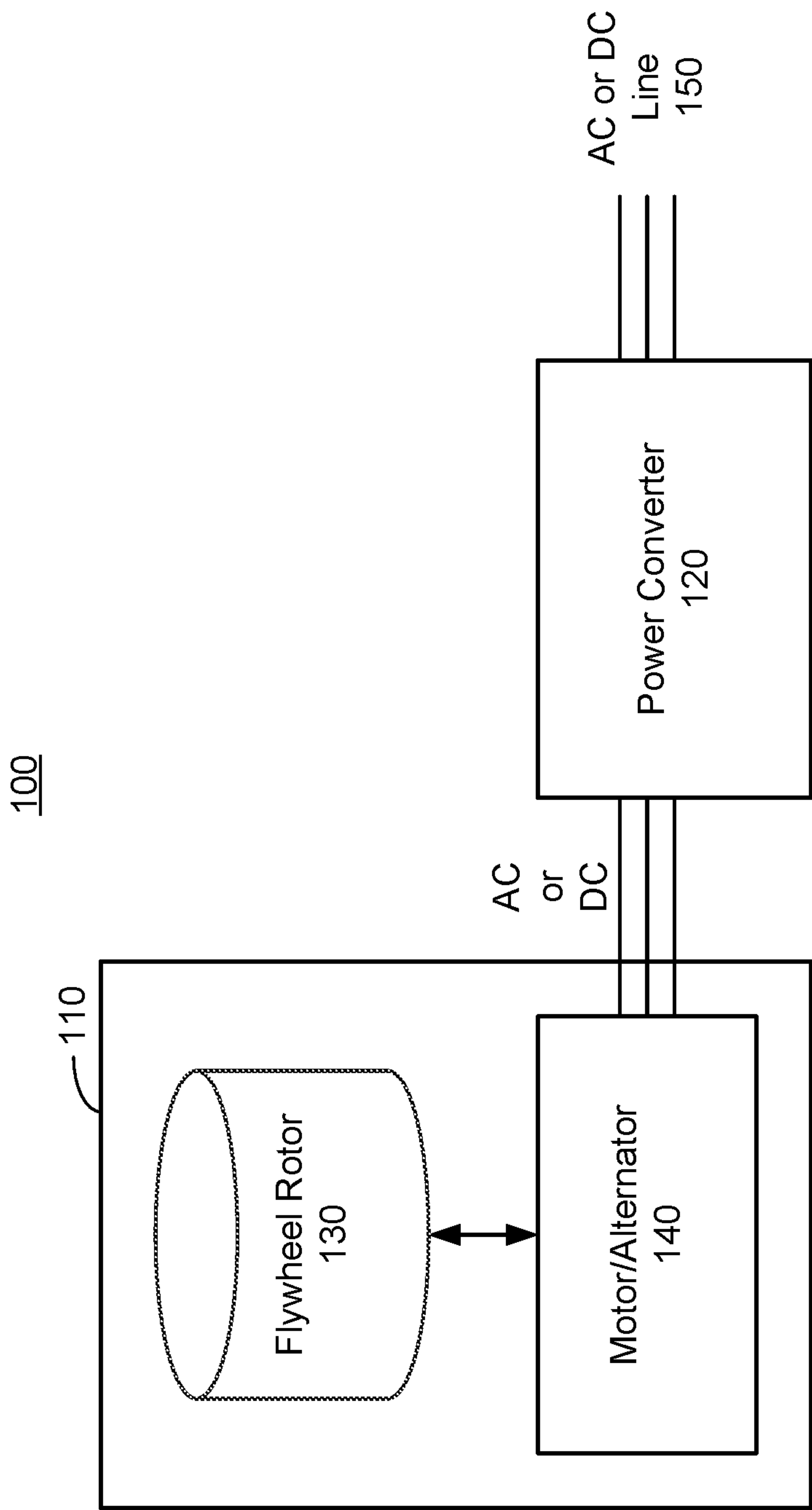


FIG. 1

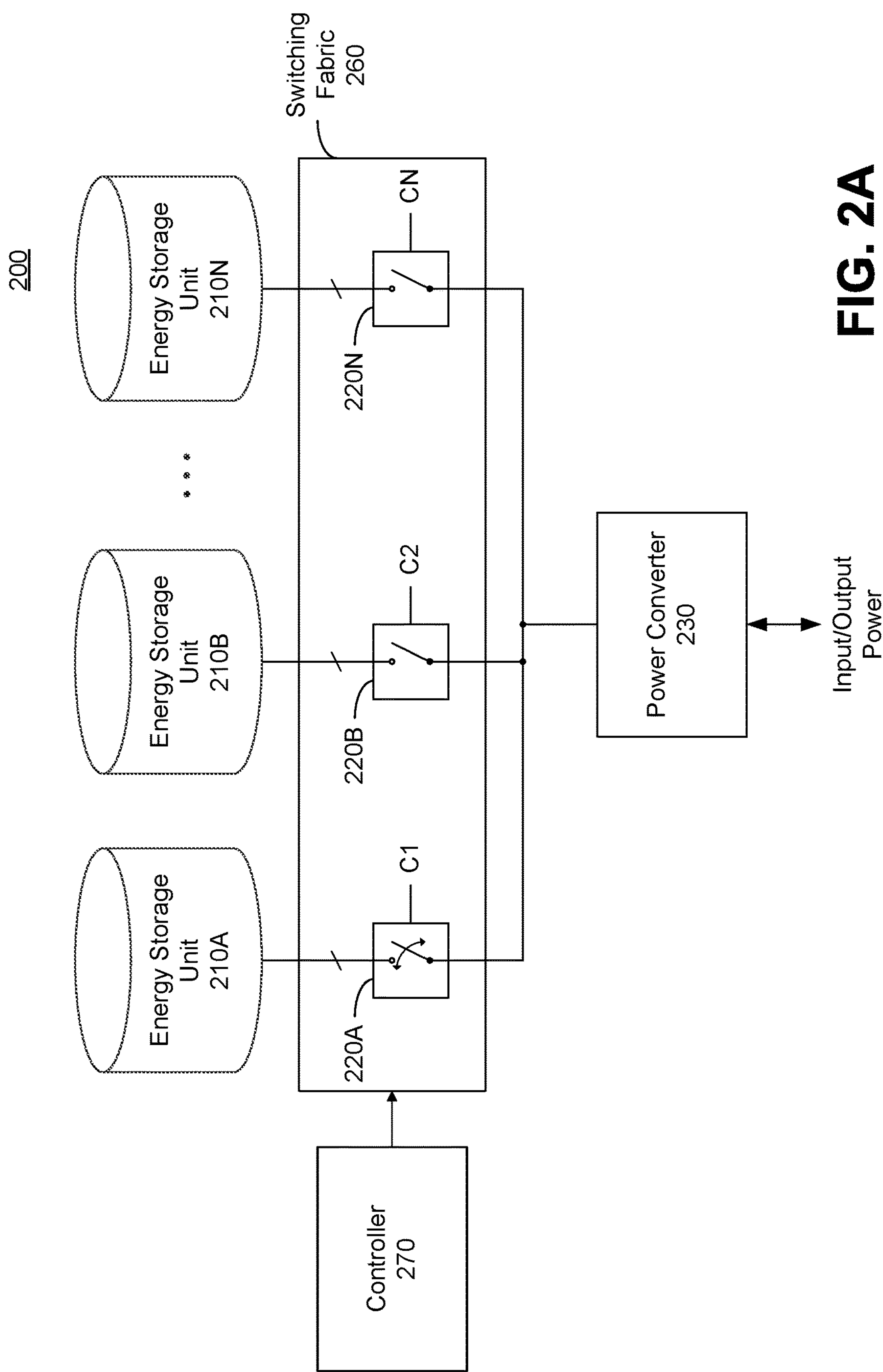


FIG. 2A

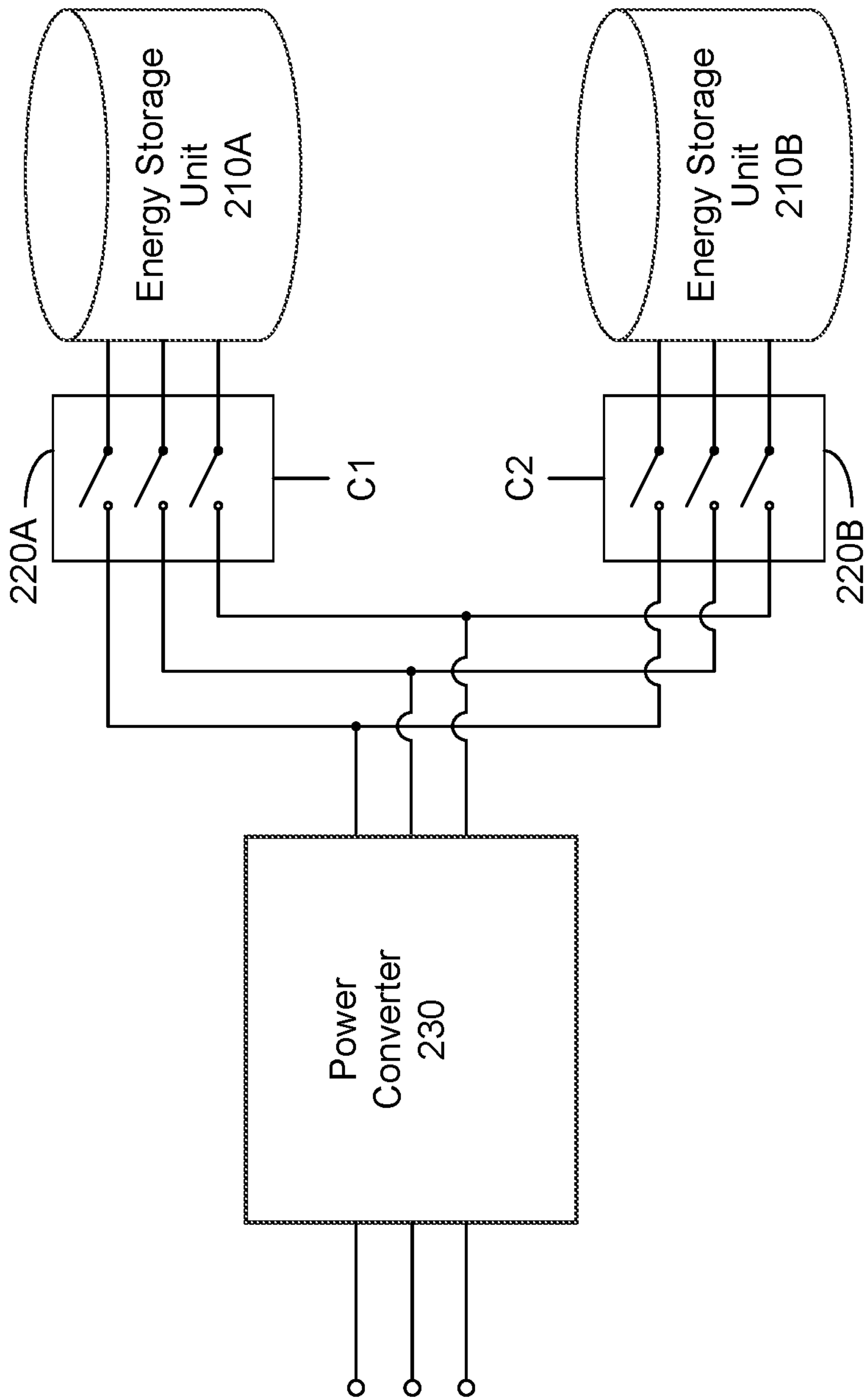


FIG. 2B

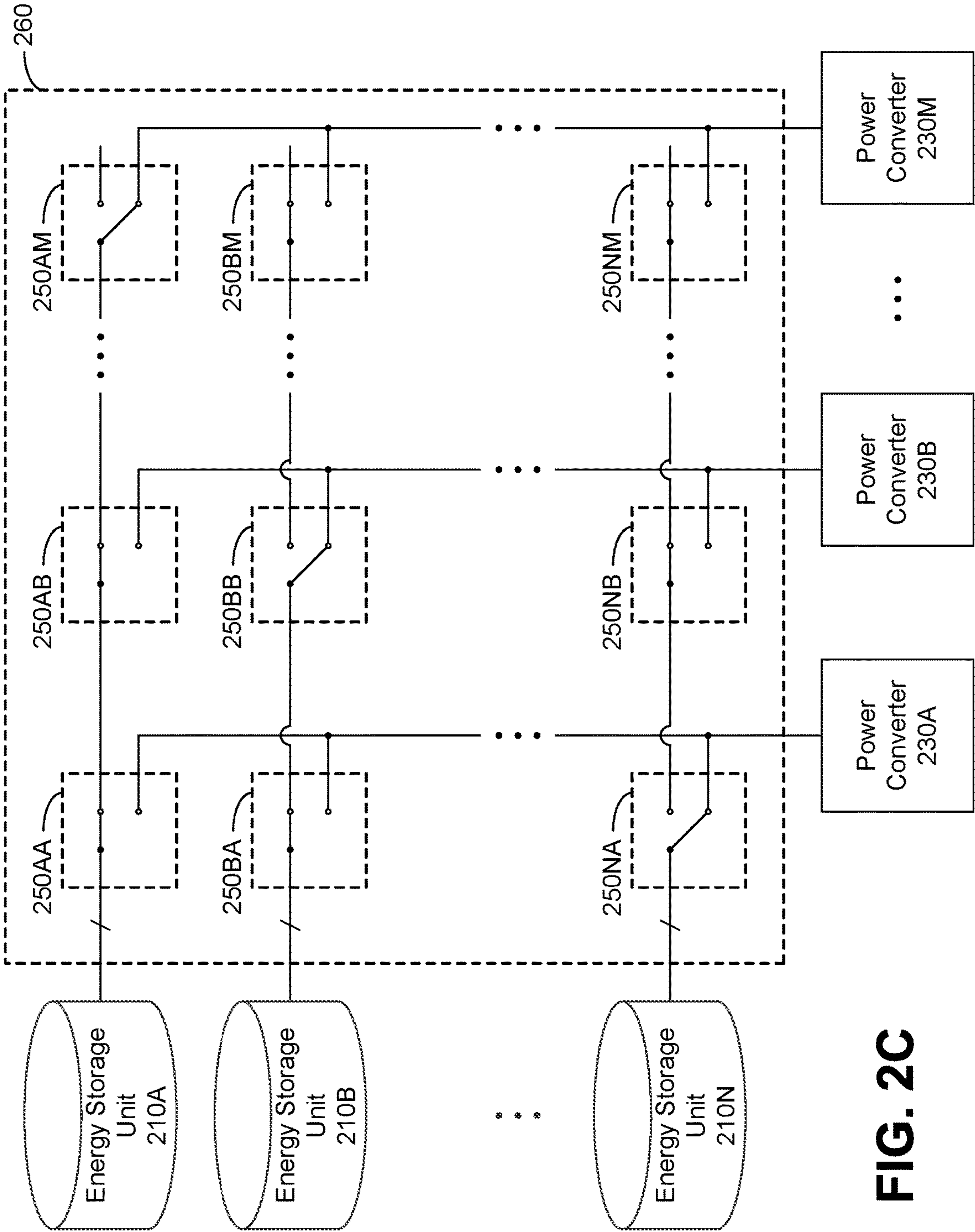
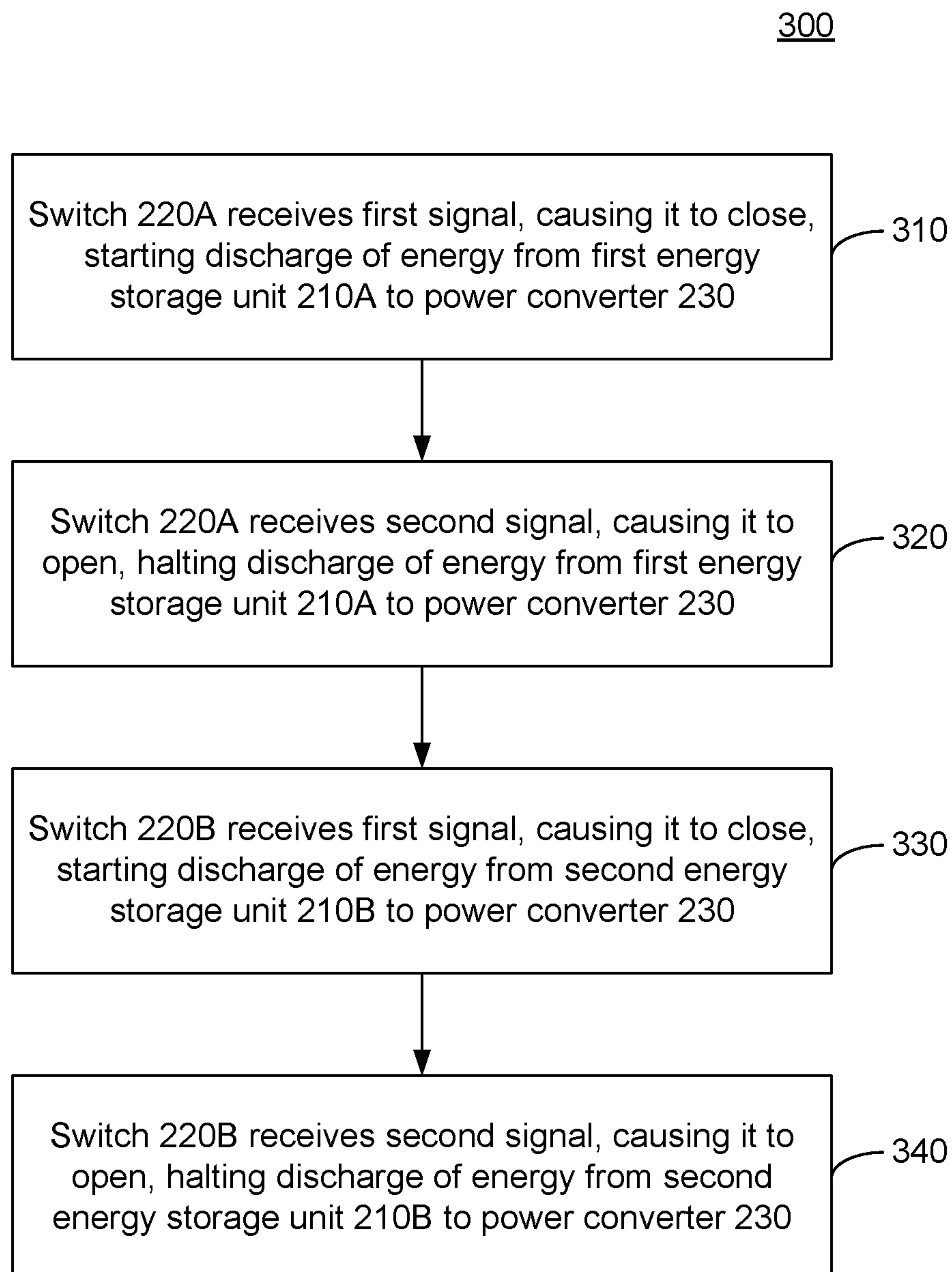


FIG. 2C

**FIG. 3**

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**SWITCHING FABRIC FOR ENERGY
STORAGE AND POWER CONVERSION**

TECHNICAL FIELD

This description generally relates to energy storage, and particularly to interconnecting multiple energy storage units in an energy storage system.

BACKGROUND

Description of the Related Art

Many energy sources, particularly clean energy sources such as wind turbines and solar panels, generate energy that does not temporally match the load experienced. In much of the developed world, energy generation follows experienced load, such that energy is provided as needed. Under circumstances of high load, techniques such as the use of peaker generators and automatic generation control (AGC) on thermal generators allow for generation that matches high and variable load. However, despite the availability of such techniques, there are often instances where energy storage is important for meeting energy load.

Currently existing energy storage systems all have drawbacks of one form or another. Size, price, storage efficiency, efficacy, and safety are all concerns when designing an energy storage unit of an energy storage system. Generally, smaller size, lower price, reduced loss in both inputting energy for storage and extracting it for distribution, reduced losses for continuous operation, and safe disposal are all preferred characteristics of energy storage units.

Additionally, energy storage systems use electrical hardware to convert the power provided by the energy storage units to an acceptable output form (e.g., 120V, 60 Hz, three-phase alternating current signal). Generally, larger circuitry, capable of handling larger amount of power is preferred.

Storage units can be designed for improved characteristics by changing the physical size and/or storage capacity of the unit. There may be preferred unit sizes or capacities that lend to improved efficiency, cost, safety, or other desired characteristics. The preferred sizes or capacities may vary between technology, application, site environment, or other considerations of the energy storage system. The preferred sizes or capacities or the storage unit may often conflict with the preferred size or rating of the electrical conversion unit, such that matching the storage unit and the power conversion unit, referred to hereinbelow as a power converter, constrains the design.

Many energy storage technologies are better suited for interfacing with AC electricity rather than DC electricity. For example, mechanical forms of energy storage such as flywheels, compressed air, pumped hydro, etc. convert electricity to mechanical energy and vice versa through the use of a motor/generator, which is typically more efficient and reliable as an AC machine. For technologies where AC electricity is the natural initial output of a storage unit, power converters are required to convert the AC output of the storage unit to a form acceptable by its application, such as DC electricity or AC electricity of a different frequency or voltage.

Multiple storage units cannot easily be connected together on a common bus, because AC electricity is incompatible between sources of different frequency. Therefore, typically, each storage unit must be connected to its own power converter.

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For purposes of reliability and cost it would be desirable for multiple storage units to connect to a single power converter or to multiple power converters through the use of a reconfigurable switching fabric. The ability to switch the flow of electric energy between storage units and power converters, referred to herein as a reconfigurable switching fabric, or simply switching fabric, affords several key advantages, as described below.

First, it allows an energy storage unit and a power converter to be independently designed and sized. The optimal size of an energy storage unit is a detailed engineering decision, and may not necessarily match the optimal size for a power converter. The switching fabric allows the storage units and power converters to be independently optimized and connected together appropriately for operation.

Second, it allows energy storage units to selectively charge or discharge to achieve improved performance as a whole system. For example, individual units may be charged or discharged in turn to balance state of charge, losses and dissipation, temperature, charge/discharge cycles, lifetime degradation, or any other desired characteristic.

Third, it improves fault tolerance and reliability by enabling many storage units and power converters to interconnect to introduce redundancy in the event of failure of any individual component.

Thus, it is with respect to these considerations and others that the present invention has been made.

SUMMARY

An energy storage system operable in a charging phase and in a discharging phase is disclosed. The energy storage system includes M energy storage units and N power converters, where M is at least two and N is at least one. The energy storage system also includes a switching fabric that reconfigurably couples the energy storage units to the power converters and a controller that reconfigures the switching fabric. The controller is capable of implementing different switching configurations during the charging and discharging phases.

BRIEF DESCRIPTION OF DRAWINGS

The disclosed embodiments have other advantages and features which will be more readily apparent from the detailed description, the appended claims, and the accompanying figures (or drawings). A brief introduction of the figures is below.

FIG. 1 is a block diagram of a flywheel energy storage system according to one embodiment.

FIG. 2A is a block diagram of multiple energy storage units connected to a single inverter, according to one embodiment.

FIG. 2B is a circuit diagram with two energy storage unit connected to a single inverter, according to one embodiment.

FIG. 2C is a block diagram of multiple energy storage units connected to multiple converters, according to one embodiment.

FIG. 3 is a flow diagram of a process for providing power by an energy storage system, according to one embodiment.

The figures depict embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated

herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

Flywheel Energy Storage System

FIG. 1 is a block diagram of a flywheel energy storage system **100** according to one embodiment. The energy storage system is operable in a charging phase, an idle phase, and a discharging phase. During the charging phase energy is provided to the energy storage system and stored in a storage element of the energy storage system. Energy may be provided by an electric power grid such as from a public utility or a micro grid, from a power station or from another energy source. As used herein the term electric power grid refers to an interconnected network for delivering electricity from suppliers to consumers and includes public utilities, micro grids and individual power generating stations. During the idle phase the energy storage system is decoupled from the energy source and energy is neither provided to the energy storage system, nor extracted from the energy storage system. During the discharging phase, the stored energy is extracted from the energy storage system (e.g., energy is extracted from the energy storage system and provided to the power grid).

The energy storage system includes an energy storage unit **110**, a power converter **120**, and an AC line **180**. Energy is stored in or drawn through an AC line **150**, such as a conventional three-phase 60 Hz line. In certain embodiments, power converter **120** converts the input alternating current into an alternating current acceptable to the motor/alternator **140**. Alternatively, in other embodiments, converter **120** converts the alternating current from the motor/alternator **140** into a direct current output.

The energy storage unit **110** includes a motor/alternator **140** and a flywheel rotor **130**. The motor/alternator **140** converts between electrical and mechanical energy, so that energy can be stored in or drawn from the flywheel rotor **130**. The motor/alternator **140** is physically coupled to the flywheel rotor **130** either directly or indirectly using a shaft. The motor/alternator **140** is coupled to the remainder of the system **100** via wires or other electrical couplings. Generally, although only one of each component is shown, in practice a flywheel energy storage system **100** may include multiples of each individual component.

It may be appreciated by one skilled in the art that while energy storage unit **110** is illustrated and described hereinabove as a flywheel-based energy storage system, the invention is not so limited. Energy storage unit **110** may be based on any energy storage technology, including inter alia solar cells, wind turbines, hydroelectric, and battery. Thus, the illustrative example of a flywheel-based energy storage unit is not intended to be limiting on the underlying technology used for this purpose.

Switching Fabric

FIG. 2A illustrates an energy storage system **220** multiple energy storage units connected to a single power converter **230**, according to one embodiment. The diagram of FIG. 2A shows multiple energy storage units (e.g., N energy storage units, where N is an integer number greater or equal than 2) including a first energy storage unit **210A**, a second energy storage unit **210B**, and an n-th energy storage unit **210N** connected to a power converter **230** via a switching fabric **260**. The switching fabric reconfigurably couples each energy storage unit **210** to the power converter **230**. The switching fabric includes N switches **220A-220N**.

The first energy storage unit **210A** is connected to a first switch **220A**, the second energy storage unit **210B** is connected to a second switch **220B**, and the n-th energy storage unit **210N** is connected to an n-th switch **220N**. The first switch **220A** is controlled by a first control signal C1, the second switch **220B** is controlled by a second control signal C2, and the n-th switch **220N** is controlled by an n-th control signal CN. All switches are then connected to the input of a single power converter **230**. Energy storage system **200** may include a controller **270** that generates the control signals C1 through CN that control each of switches **220A-220N** of switching fabric **260**. Using signals C1 through CN, the controller is capable of reconfiguring the switching fabric to couple any energy storage unit(s) to the power converter **230**.

Power converter **230** of energy storage system **200** may then be connected to an electric power grid. Energy storage units **210A-210N** are charged using energy drawn from the electric power grid. The energy storage system **200** also provides energy to the electric power grid (e.g., when there is a shortage of power or to stabilize the electric power grid).

Controller **270** manages the switching of power between energy storage unit **210A-210N** and power converter **230** by issuing signals to open and close via control signals C1-CN to switches **220A-220N** that controls the charging and discharging process. Controller **270** may include additional signals for monitoring or control. In certain embodiments, controller **270** is implemented with digital electronics components that include a processor and non-volatile memory for storing program code and data. The processor may be a general purpose processor or microprocessor, a field programmable gate array (FPGA), or other programmable or configurable electronics component. In addition to controlling the switching of power, controller **270** may perform additional functions such as inter alia receiving data from sensors, monitoring the state of charge, controlling associated sub-components, recording data, and receiving control signals,

In certain embodiments, switching fabric **260** and controller **270** are implemented in the same device or electronics unit. In other embodiments they are separate units. Although controller **270** is not shown in FIGS. 2B and 2C hereinbelow, it may be appreciated that in general controller **270** implements a switching policy, i.e. the logic that controls the opening and closing of switches in switching fabric **260**.

In some embodiments, the design of the energy storage units attempts to optimize the relationship between amount of energy that can be stored and the price of manufacturing the storage unit. For instance, for a flywheel rotor, the price of manufacturing a rotor may increase faster than linear for as the energy storage capabilities of the energy storage unit increases. That is, for larger energy storage capabilities, it might be more cost effective to manufacture two smaller energy storage units with half of the total energy storage capability instead of one larger energy storage unit. For instance, for a system with an total energy storage capability of 40 kWh, it may be more cost effective to manufacture two energy storage units, each having an energy storage capability of 20 kWh, instead of manufacturing one energy storage unit having an energy storage capability of 40 kWh.

In some cases, it may be more cost effective to manufacture a larger converter unit having a larger power output than manufacturing multiple smaller converter units each having a fraction of the power output of the larger converter unit. For instance, for a system with a power capability of 10 kW, it may be more cost effective to manufacture a single

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converter unit with a power output of 10 kW, instead of two converter units, each with a power output of 5 kW.

As such, the power capability of system **200** is determined by the power output of the single converter unit **230** while the energy storage capability is determined by the cumulative energy storage capability of energy storage units **210A-210N**.

To operate energy storage system **200** of FIG. 2A, switches **220A-220N** are controlled so that at most one switch is closed at any given time. The switches may be sequentially closed and opened to allow access to each individual energy storage unit **210**. There are three main operations that can be performed by the energy storage system **200**: (i) charging, (ii) idling, and (iii) discharging.

To charge energy storage system **200**, energy storage units **210** are sequentially charged. To charge first energy storage unit **210A**, first switch **220A** is closed while switches **220B** and **220N** are open, and power is supplied through the power converter **230**. When first energy storage unit **210A** is charged, first switch **220A** is opened. Similarly, to charge the second energy storage unit **210B**, second switch **220B** is closed while the switches **220A** and **220N** are open, and power is supplied through power converter **230**. When second energy storage unit **210B** is charged, second switch **220B** is opened. This process is repeated for each energy storage unit **210** of energy storage system **200**.

During the idle phase, after the storage units **210** are charged, every switch **220A-220N** is kept open. During this phase, power is neither input, nor output through power converter **230**.

To discharge energy storage system **200**, each of the energy storage units **210** is sequentially discharged. That is, the switching fabric **260** is reconfigured to couple the energy storage units **210** to the power converter in a time-multiplexed fashion. For instance, first energy storage unit **210A** may be discharged first, followed by second energy storage unit **210B** and so forth. To discharge the first storage unit **210A**, first switch **220A** is closed to couple first storage unit **210A** to power converter **230**, while switches **220B** and **220N** are open.

Generally, if the first energy storage unit has an energy storage capacity of $E1$, and the power converter has a power rating of P , the first energy storage unit may be discharged for an amount of time $T1$ equal to:

$$T1 = \frac{E1}{P} \quad (1)$$

For instance, if first energy storage unit **210A** has an energy storage capacity of 20 kWh, and power converter **230** has a power rating of 10 kW, then first energy storage unit **210A** may be discharged for 2 hours.

Similarly, to discharge the second energy storage unit, the second switch **220B** is closed while the other switches **220A** and **220N** are open. By closing the second switch **220B**, the second energy storage unit **210B** is coupled to the power converter **230**. This process may be repeated for each energy storage unit until every energy storage unit is discharged, or until power from the energy storage system is no longer needed.

Energy storage system **200** may provide power for an amount of time equal to:

$$T_{total} = \sum_{k=1}^N \frac{Ek}{P} \quad (2)$$

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where Ek is the energy storage capacity of the k -th energy storage unit, and P is the power rating of the power converter **230**.

In some embodiments, the sequence in which the energy storage units are discharged may improve operational performance; for example, by balancing state of charge, loss dissipation, charging/discharging cycles, or other characteristics among a set of energy storage units.

FIG. 2B illustrates a circuit diagram for an embodiment of energy storage system **200** with two energy storage units **210A-210B** and a single power converter **230**. Although only two energy storage units **210A** and **210B** are shown in the energy storage system of FIG. 2B, any number of energy storage units may be used instead.

In the example of FIG. 2B, each energy storage unit **210** outputs three-phase AC power. Each energy storage unit **210A** and **210B** is connected to a switch **220A** or **220B**, respectively. Since energy storage units **210** output a three-phase signal, each energy storage unit **210** is connected to a triple pole, single throw (3PST) switch. In some embodiments, other configurations, such as a triple pole, triple throw (3P3T) switch may be used. Switches **220A** and **220B** are then connected to a power converter **230**. There are a wide variety of embodiments of power converter **230**. For example, in one embodiment, power converter **230** may include two back to back three-phase full-wave bridge rectifiers and a capacitor. In other embodiments, a three-phase full-wave inverter using a center-tapped transformer, or a three-phase half-wave inverter, may be used. Further, power converter **230** may convert the three-phase AC power from energy storage units **210A** and **210B** to a different output form, e.g. DC power. Thus, while power converter **230** is illustrating as having 3 output lines, in fact this may be 1, 2, 3 or another number of output lines as required by the electric power grid or other energy network to power converter **230** connects.

FIG. 2C illustrates an embodiment of energy storage system **200** with N energy storage units **210A-210N** and M power converters **230A-230M**. Each of the N energy storage units **210A-210N** is connectable to each of the M power converters **230A-230M** via switching fabric **260**. In some embodiments, the number N of energy storage units **210** is larger than the number M of power converters **230**. In other embodiments, M may be greater than N . In yet other embodiments, N or M may be 1, i.e. there may be a single energy storage unit **210** or a single power converter **230**.

In some embodiments, during the discharging phase of the energy storage unit **200**, not more than one energy storage unit **210** is simultaneously coupled to any power converter **230**. That is, the switching fabric **260** may be a blocking switching fabric. Alternatively, one energy storage unit **210** may be simultaneously coupled to more than one power converter **230**. That is, the switching fabric **260** may be a non-blocking fabric.

In some embodiments, during the charging phase, not more than one power converter can be simultaneously coupled to each energy storage unit. In other embodiments, one power converter **230** may be simultaneously coupled to more than one energy storage unit **210**.

Referring back to the diagram of FIG. 2C, energy storage unit **210A** is coupled to M switches **250AA** through **250AM**. In the embodiment of FIG. 2C, the M switches are double throw switches connected in series. In other embodiments, single throw switches connected in parallel may be used instead. Additionally, in the diagram of FIG. 2C a single line is used to depict all the phases of the AC signal. In the case that energy storage unit **210** outputs a three-phase AC signal,

three power lines emerge from energy storage unit **210**, one for each phase of the AC signal, and switches **250** are triple pole switches, one pole for each phase of the AC signal.

Switch **250AA** is connected to power converter **230A**, switch **250AB** is connected to power converter **230B**, and so on. Similarly, energy storage unit **210B** is coupled to M switches **250BA** through **250BM**, where switch **250A** is connected to power converter **230A**, switch **250BA** is connected to power converter **230B**, and so on. This configuration is repeated for each of the energy storage units. That is, each energy storage unit **210** is coupled to M switches, and each of the M switches is connected to a different power converter **230**.

During operation of energy storage system **200**, a given energy storage unit **210** may be connected to at most one power converter **230**, and any given power converter **230** may be connected to at most one energy storage unit **210**. For instance, to charge or discharge the first energy storage unit **210A**, one of the switches **250AA-250AM** is closed, i.e. it allows energy to flow to a corresponding power converter **230**. If switch **250AA** is closed, power converter **230A** is used to charge or discharge energy storage unit **210A**. Alternatively, if switch **250AB** is closed, power converter **230B** is used to charge or discharge energy storage unit **210A**.

In the embodiment of FIG. 2C, controller **260** implements a switching policy that controls M×N switches in real-time. Thus, switching fabric **260** is reconfigured in real-time to implement a specific switching policy. This approach beneficially increases reliability of the energy storage system **200**. Having multiple power converters and multiple energy storage units add redundancy to the system. If any of the energy storage units **210A-210N** or power converters **230A-230M** malfunctions, the failing energy storage unit or power converter can be taken offline for maintenance without impacting the performance of the energy storage system.

FIG. 3 is a flow diagram of a method **300** for providing power by an energy storage system, according to one embodiment. The switching policy in process **300** is implemented by controller **270**. Thus, switching fabric **260** may be considered to be reconfigurable as controller **270** may implement a wide variety of switching policies, including inter alia those described herein. Generally, method **300** corresponds most directly to the steps performed by the switching fabric **260** illustrated in FIG. 2B, although it also applies to FIGS. 2A and 2B as well.

Generally, method **300** illustrates a sequence of steps performed by energy storage system **200**, under the control of controller **270**, to extract energy from two energy storage units.

At step **310** a signal is received from control signal C1 by switch **220A** which causes switch **220A** to close, thus enabling energy to discharge from a first energy storage unit **210A** to power converter **230**. The discharging phase continues for a period of time until energy storage unit **210A** is fully or partially discharged. Then, at step **320** a second signal is received from control signal C1 by switch **220A** that causes switch **220A** to open, thus halting the discharge of energy from energy storage unit **210A**. Energy flowing through power converter **230** during the discharging phase may, for example, be converted to a 120V, 60 Hz three-phase AC signal.

Next, at step **330**, a signal is received from control signal C2 by switch **220B** which causes switch **220B** to close, thus enabling energy to discharge from a second energy storage unit **210B** to power converter **230**. The discharging phase continues for a period of time until energy storage unit **210B**

is fully or partially discharged. Then, at step **340** a second signal is received from control signal C2 by switch **220B** that causes switch **220B** to open, thus halting the discharge of energy from energy storage unit **210B**.

For instance, if first energy storage unit **210A** can store 20 kWh of energy and the second energy storage unit **210B** can store 20 kWh of energy, and the energy storage system outputs power at 10 kW (i.e., the power converter can output power at 10 kW), then the energy storage system may run for 4 hours (20 kWh/10 kW+20 kWh/10 kW=4 h). In this exemplary system, the first energy storage unit **210A** may be discharged for the first 2 hours with a power output of 10 kW, and the second energy storage unit **210B** may be discharged for the second 2 hours with a power output of 10 kW.

Additional Configuration Considerations

Even though flywheel rotors are used as an example of an energy storage unit, other types of energy storage units may be used. For instance, energy storage units storing thermal energy, compressed air, or geothermal energy may be used instead. Further, an energy storage system may use energy storage units that store energy in different forms. For example, an energy storage system may include an energy storage unit that stores kinetic energy in a rotor, and an energy storage unit that stores energy as compressed air.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs through the disclosed principles herein. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

The invention claimed is:

1. An energy storage system operable in a charging phase and in a discharging phase, the energy storage system comprising:

N energy storage units, wherein N is at least two, the energy storage units configured to output a three-phase AC signal;

M power converters, wherein M is at least one; and a switching fabric that reconfigurably couples energy storage units to power converters, wherein the switching fabric is configured to receive and switch a three-phase AC signal.

2. The energy storage system of claim 1, further comprising:

a controller that controls the charging phase and discharging phase.

3. The energy storage system of claim 2, wherein the switching fabric comprises:

N×M switches such that each energy storage unit of the N energy storage units is connected to each power converter of the M power converters via a different switch; and

a control signal connected to each switch that receives a control signal from the controller that indicates if the switch is to be opened or closed.

4. The energy storage system of claim 2, wherein the controller is capable of reconfiguring the switching fabric to couple any energy storage unit to any power converter.

5. The energy storage system of claim 2, wherein, during the discharging phase, the controller reconfigures the

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switching fabric to couple at least two energy storage units of the plurality of energy storage units to a power converter of the plurality of power converters in a time-multiplexed fashion.

6. The energy storage system of claim 2, wherein the controller reconfigures the switching fabric in order to balance energy storage among the N energy storage units.

7. The energy storage system of claim 1, wherein the number of energy storage units in the plurality of energy storage units is greater than the number of power converters in the plurality of power converters.

8. The energy storage system of claim 1, wherein M is at least two.

9. The energy storage system of claim 1, wherein the energy storage system is coupled to an electric power grid.

10. The energy storage system of claim 1, wherein, during the discharging phase, not more than one energy storage unit of the N energy storage units can be simultaneously coupled to each power converter of the M power converters.

11. The energy storage system of claim 1, wherein, during the discharging phase, each energy storage unit of the N energy storage units can be simultaneously coupled to more than one power converter of the M power converters.

12. The energy storage system of claim 1, wherein, during the charging phase, not more than one power converter of the M power converters can be simultaneously coupled to each energy storage unit of the N energy storage units.

13. The energy storage system of claim 1, wherein, during the charging phase, each power converter of the M power converters can be simultaneously coupled to more than one energy storage unit of the N energy storage units.

14. The energy storage system of claim 1, wherein the switching fabric is blocking.

15. The energy storage system of claim 1, wherein the switching fabric is non-blocking.

16. The energy storage system of claim 1, wherein the energy storage system outputs three-phase AC electricity with a frequency of 50 or 60 Hz.

17. The energy storage system of claim 1, wherein, during the discharging phase, the M power converters receive AC electricity from the N energy storage units and output DC electricity.

18. The energy storage system of claim 17, further comprising:

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a second plurality of power converters coupled to the N power converters, the second plurality of power converters configured to convert the DC electricity to AC form at a predetermined frequency.

19. The energy storage system of claim 1, wherein, during the discharging phase, the plurality of power converters receive AC electricity from the plurality of energy storage units and output electricity in AC form at a predetermined frequency.

20. The energy storage system of claim 1, wherein the N energy storage units store energy using flywheel rotors.

21. The energy storage system of claim 1, wherein the N energy storage units store energy using a compressed fluid.

22. The energy storage system of claim 1, wherein all energy storage units of the N energy storage units store energy using the same physical mechanism.

23. The energy storage system of claim 1, wherein at least two energy storage units of the N energy storage units store energy using different physical mechanisms.

24. The energy storage system of claim 1, wherein at least two energy storage units of the N energy storage units have different energy storage capacities.

25. The energy storage system of claim 1, wherein at least two power converters of the M power converters have different power ratings.

26. A method for operating energy storage units in an energy storage system, comprising:

configuring a switching fabric to electrically couple a first energy storage unit to a power converter, the first energy storage unit configured to discharge via a three-phase AC signal;

maintaining the electrical coupling between the first energy storage unit and the power converter for a first predetermined amount of time;

reconfiguring the switching fabric to electrically couple a second energy storage unit to the power converter, the second energy storage unit configured to charge or discharge via a three-phase AC signal; and

maintaining the electrical coupling between the second energy storage unit and the power converter for a second predetermined amount of time.

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